

Designing a Graphical User Interface for the Power Module Optimization Tool PowerSynth

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Abstract

Working under the NSF-sponsored POETS REU program, students are given the opportunity to work at the University of Arkansas on advanced research projects such as the development of a software tool called PowerSynth, which can optimize power electronic module layout. This is the first tool that automates the multi-chip power module (MCPM) design flow, and the optimization results are hardware-validated. The development of a new version of PowerSynth has required the creation of a new graphical user interface (GUI). A detailed description of the GUIs design flow and implementation is presented and directly compared to the general command line flow of PowerSynth. A discussion of the POETS REU program and the role of undergraduate research as a path to exploring new academic fields is included in its relation to the research completed at University of Arkansas.

Keywords

PowerSynth, graphical user interface, power electronics, research experiences for undergraduates, student paper

I. Introduction

In the summer of 2021, Joshua Mitchener (the first author of this paper) participated in a Research Experiences for Undergraduates (REU) program sponsored by the National Science Foundation and directed by the Engineering Research Center for Power Optimization of Electro-Thermal Systems (POETS). POETS is a network that seeks to optimize the power-to-weight ratio in all common electrical and thermal systems, including on-and-off highway vehicles and general electronics. Over the past two months, visiting undergraduate students have worked at the University of Arkansas, Fayetteville, alongside a team of graduate students on the PowerSynth tool.

II. Overview of Power Module Design Flow

Power modules have a variety of practical applications, from use in electric vehicles to personal computers. As technology continues to improve and the demand for higher-density sources of power increases, researchers are currently continuing to look for ways to optimize power module designs [1]. A typical multi-chip power module structure consists of a base plate, an insulating substrate, bonding materials, power semiconductor chips, power interconnections, encapsulant, and a case. As more expensive materials such as silicon carbide (SiC), gallium nitride (GaN) become more widely available for use in power modules, power module fabrication continues to

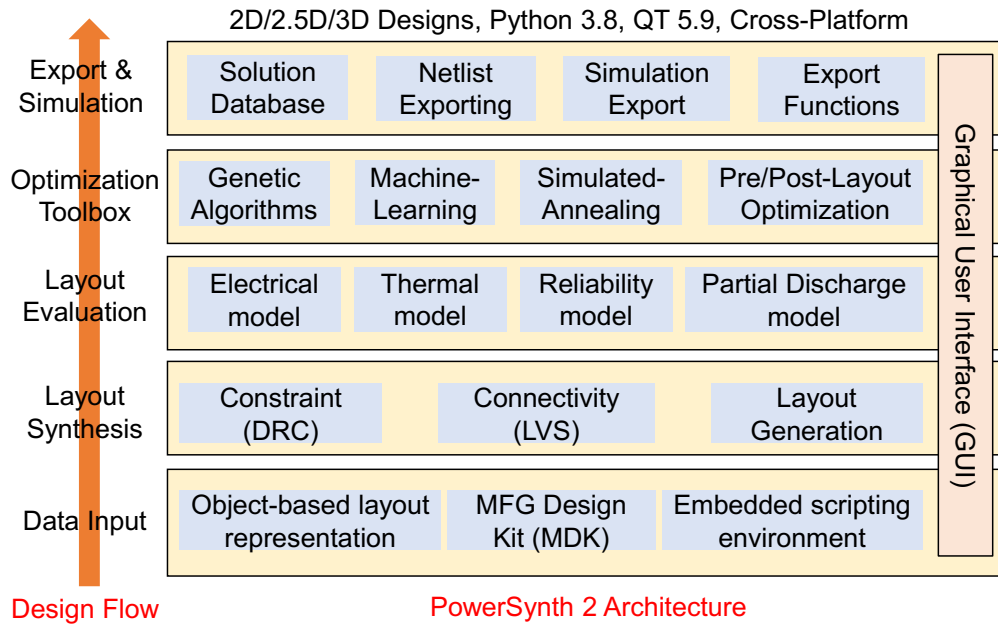


Fig. 1 PowerSynth 2 architecture

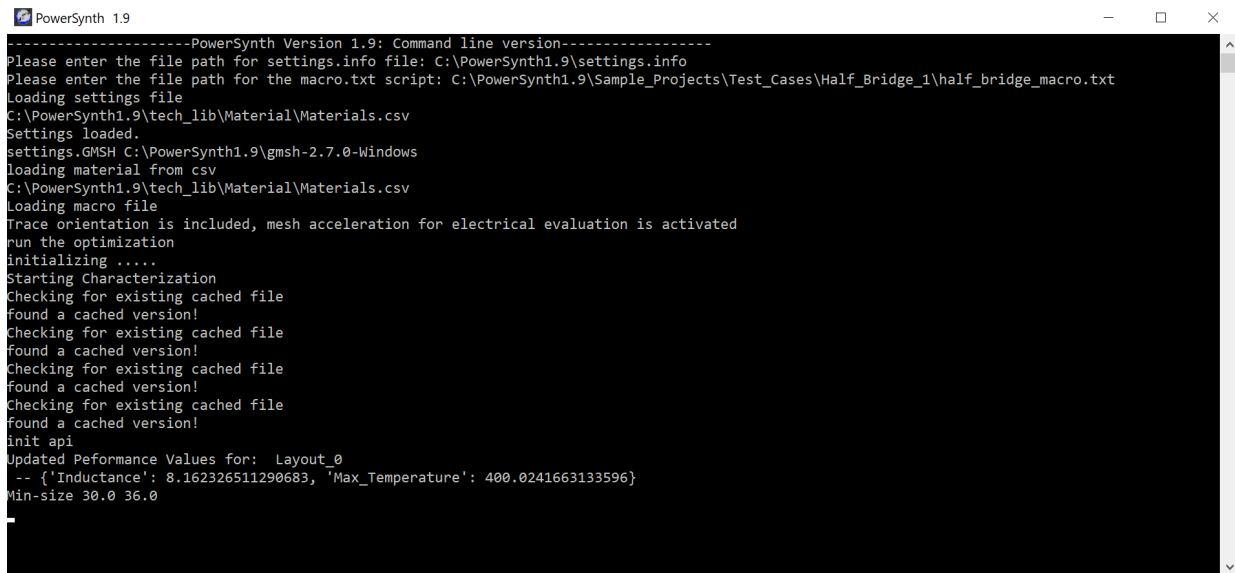
advance in its performance [2]. A power module's layout is one of the most important features in establishing its electrical, thermal, and mechanical capabilities. The layout is carefully optimized based on the materials selected for use in the module, the attachment strategy for connecting wires, and the layer structure from the base plate to the die and housing [3]. A variety of relatively new packaging technologies for power modules are currently available to take advantage of the benefits of wide-bandgap (WBG) devices [5]. However, some of the most common package structures with SiC devices are inherently limiting to maximizing performance. When creating a power module layout, finding a balance between electrical parasitics and thermal dissipation is crucial. To minimize the heat loss, the copper trace area should be as large as possible, yet parasitics must be minimized by limiting the power loop area. Besides these, mechanical stress and strain factors also need to be considered for reliable operations. Thus, electro-thermo-mechanical optimization of a module is essential before fabrication [3]. In the industry, the MCPM design flow is still a manual and iterative process [11] and takes weeks to complete. However, with the increasing complexity of the MCPM layouts, the manual design process cannot quickly reach a global optimum solution. Thus, the development of design automation tools is a goal for power electronics researchers. Research and development of PowerSynth are on-going to facilitate the designers with a multi-objective optimization framework that can generate a Pareto-front from a wide variety of solutions with a significant speedup [9].

III. Overview of the PowerSynth Project

Currently, PowerSynth is a layout synthesis tool for multi-chip power module designs that creates a variety of optimized designs according to the user's specified parameters [6]. The tool is created to address, and combat issues that have arisen as MCPM designs have become denser, resulting in the signal integrity of power modules becoming more likely to be compromised [7]. While other software tools, such as the Finite Element Method (FEM) or 3D field solver, that serve a similar purpose to PowerSynth exist in the market, PowerSynth seamlessly combines layout synthesis

with design optimization together into a single process. It is also designed to perform orders of magnitude more efficiently with a minimal cost to the accuracy of results. For example, other tools or methods for optimizing a design may take weeks to complete, whereas an experienced user of PowerSynth can optimize a layout within hours [6].

Though the previous versions of PowerSynth had a GUI to assist the user with the process of using the tool [9], a new PowerSynth 2 series is currently in development, introducing new features that require a new interface. This new version of PowerSynth is being built from the ground up and includes more advanced and efficient algorithms to optimize power module designs. A new hierarchical structure has been adapted for representing 2D/2.5D/3D MCPM layouts. Thus, it would be effective to create a new GUI that is both designed to mirror the new architecture (shown in Fig. 1) and flow of PowerSynth and is able to support the new features offered by the tool.



```

PowerSynth 1.9
-----PowerSynth Version 1.9: Command line version-----
Please enter the file path for settings.info file: C:\PowerSynth1.9\settings.info
Please enter the file path for the macro.txt script: C:\PowerSynth1.9\Sample_Projects\Test_Cases\Half_Bridge_1\half_bridge_macro.txt
Loading settings file
C:\PowerSynth1.9\tech_lib\Material\Materials.csv
Settings loaded.
settings.GMSH C:\PowerSynth1.9\gmsH-2.7.0-Windows
loading material from csv
C:\PowerSynth1.9\tech_lib\Material\Materials.csv
Loading macro file
Trace orientation is included, mesh acceleration for electrical evaluation is activated
run the optimization
initializing .....
Starting Characterization
Checking for existing cached file
found a cached version!
Checking for existing cached file
found a cached version!
Checking for existing cached file
found a cached version!
Checking for existing cached file
found a cached version!
Checking for existing cached file
found a cached version!
init api
Updated Performance Values for: Layout_0
-- {'Inductance': 8.162326511290683, 'Max_Temperature': 400.0241663133596}
Min-size 30.0 36.0

```

Fig. 2 Screenshot of the current command line version of PowerSynth

IV. Design Flow of Command Line Version

The current command-line version of PowerSynth follows a very simple flow but requires a large amount of setup. The user must manually create a variety of files to be processed by PowerSynth, and the paths to these files must be explicitly included in the macro script file. One of the most important files to be created is the layout script, which contains the hierarchy information of traces, devices, leads, and all other elements that will make up the specific layout. This file also contains paths to parts files that specify the attributes of each material. The names of traces and bondwire in this file will be the reference in the bond wire setup and trace orientation files.

There are two more files required for the main flow of PowerSynth (excluding the macro script file): the layer stack file and the bond wire setup. The bond wire setup essentially provides the specifics on the materials, sizes, and placements of the bondwire within the module. The layer stack is a CSV file that contains the sizes, thicknesses, and materials of different layers in the module structure. If the user chooses to run layout solution generation with an electrical setup, then they will also need to create a trace orientation file that denotes the current flow direction



Fig. 3 The opening window of the new PowerSynth GUI

through the corresponding trace. Even more specifically, if the user runs layout solution generation with the PowerSynth built-in model, then they must create and reference the path to a pre-compiled parasitic model file.

Finally, the user must create the macro script file with proper paths to each of the previous files. This file includes various options for running PowerSynth, including but not limited to the number of layouts to create, whether to apply reliability constraints, whether to plot the solution, the layout mode, the randomization seed, and the electrical and thermal setups. The electrical setup requires a device connection, where the current flow (i.e., drain to source, gate to source, etc.) must be specified for each device, as well as the general frequency for the layout. Similarly, for the thermal setup, the user must specify the power for each selected device alongside general parameters such as heat convection coefficient and ambient temperature.

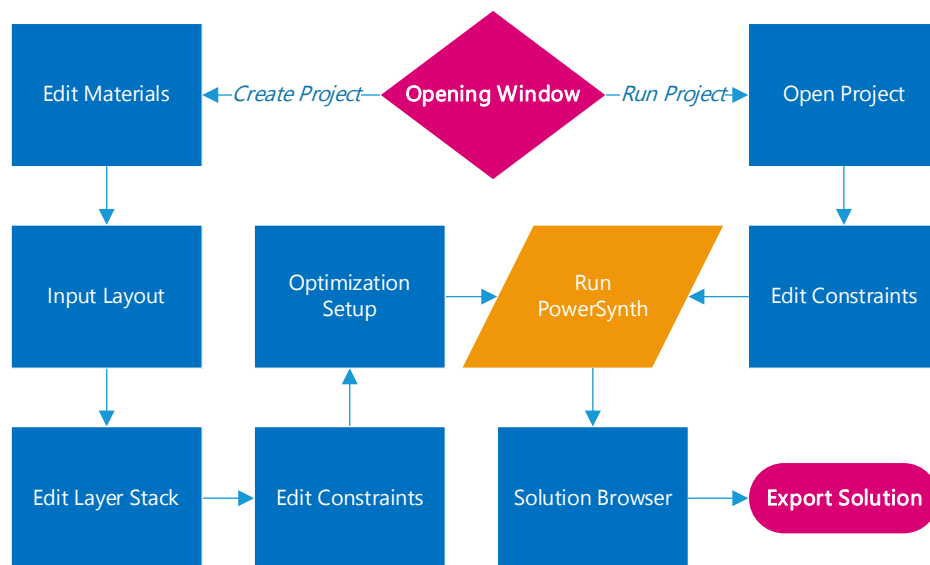


Fig. 4 PowerSynth 2 GUI design flow

With the general setup of a project now completed, the user will first be directed to provide the necessary configuration information through a text file that contains essential paths for PowerSynth, including but not limited to where to export data, the path to external models/tools, the technology library, and the material library. After setting up the environment, the user will be directed to input the path to their macro script (shown in Fig. 2). Finally, PowerSynth will automatically create a constraints file and will prompt the user to edit these constraints before generating solutions. It should be noted that this constraints file can be reused or created by the user and that this step can be bypassed by setting the “New” flag to 0 in the macro script. PowerSynth will then run the project and export the created solutions to the specified directory.

V. Design Flow Using the Graphical User Interface

A. Overview

The PowerSynth GUI is implemented as a series of windows created with a QT Framework (currently implemented through PySide2) that are connected via Python. The flow (shown in Fig. 4) is intentionally designed to require users to proceed linearly through the interface without giving users the ability to revise any of their input without restarting the GUI. The interface is also intended to be both simple and functional, only showing what is absolutely necessary to the user to run PowerSynth. Currently, the PowerSynth GUI is able to edit and track three of the five required files, with two of the files being automatically generated for the user. Future versions of the PowerSynth GUI are planned to include more advanced features and implementations.

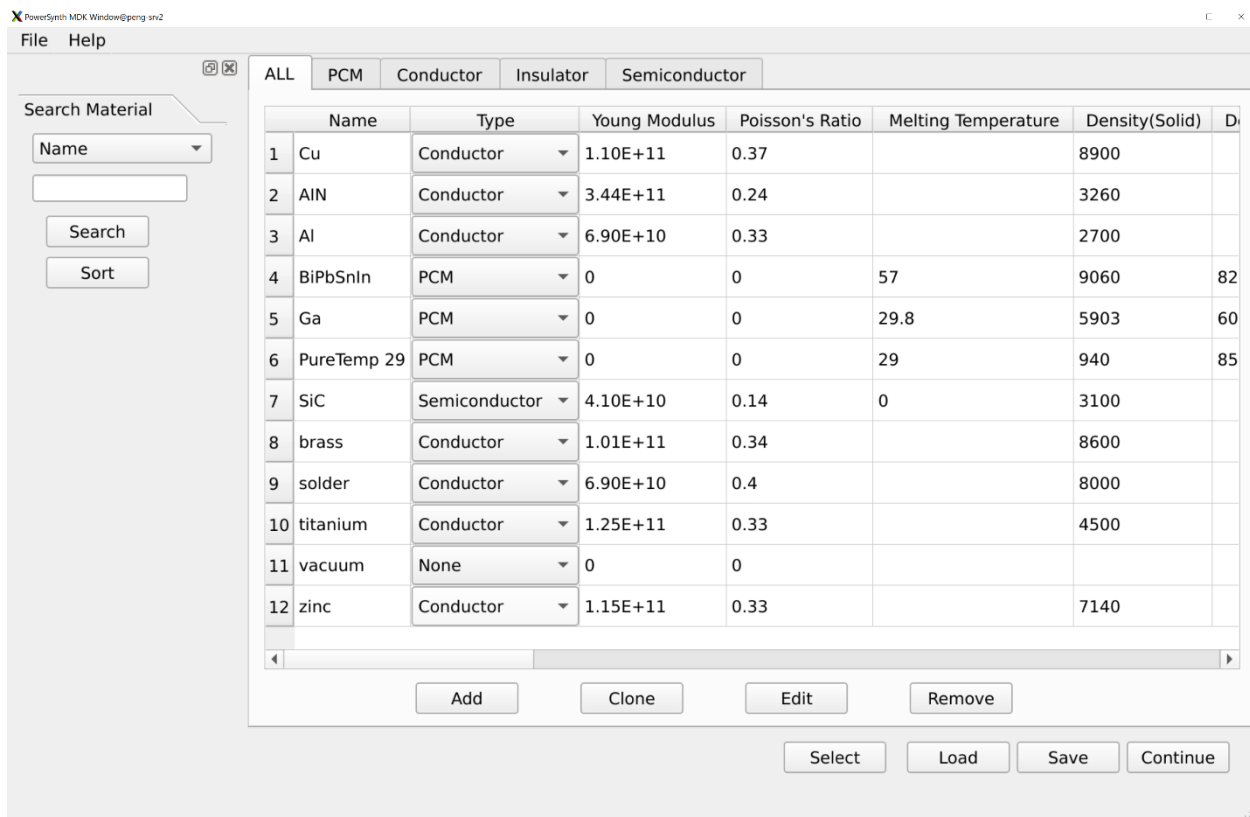


Fig. 5 Main window of the MDKEditor

B. Data Input

The opening window of the user interface provides two main flows: to create a project from an existing layout or to run a project that is already properly configured (Fig. 3). A button to access the user manual for PowerSynth 1.9 is also provided at this stage. If the user decides to create a new project, they will be prompted to create or adjust the materials list. They may choose to either use the default materials or to edit the materials list by opening the MDKEditor (Fig. 5). The MDKEditor is a material library editor that allows for quick customization and importing/exporting of materials.

After finalizing the selected materials for their project, the user will be required to enter the paths (or use the available file explorers) to three required files: the layout geometry description script, the layer stack, and the bond wire setup information. These files are essential for creating a project, as each is related to the certain step of describing the initial module design structure. The user is also prompted to select whether to apply reliability constraints at this stage, as the GUI will automatically create the constraints file for the user after this window.

✕ Edit Layer Stack@peng-xyz ✕

Please edit the values in the layer_stack.csv file, then click continue.

	Name	Origin	Width	Length	Thickness	Material	Type	Electrical
1	Baseplate	0,0	53	57	1	copper	p	F
2	Bottom_Metal	5,5	43	47	0.2	copper	p	G
3	Ceramic1	5,5	43	47	0.835	Al_N	p	D
4	I1	5,5	43	47	0.2	copper	p	S
5	C1		43	47	0.18	None	a	C

Continue

Fig. 6 Visualization of the layer stack

C. Layout Synthesis

Assuming all paths are provided correctly, the interface will now provide a visualization of the input layer stack file (Fig. 6). If the user wishes to make any edits to the layer stack, they can simply edit this table, and its contents will be written back to the layer stack file for later use. Similarly, when the user continues, the interface will have created a constraints file for the user and will show a visualization of this file in the same tabular format as the layer stack (Fig. 7).

D. Layout Solution Generation/Optimization

Finally, the user will now input the required options for running PowerSynth to be included in the macro script file. They must first decide how they would like to run the tool, either with initial layout evaluation, with layout solution generation only, or with optimization. This will determine what options the interface will present to the user in the next window. Supposing the user selects both layout optimization and evaluation, the user will be presented with a variety of options to be adjusted regarding evaluation as well as two buttons to open the electrical and thermal setups (Fig. 8). All the options presented in the GUI at this stage directly correspond to a required line in the macro script file for running PowerSynth, and the macro script file will be automatically generated by the interface once all setups have been completed.

Please edit the values in the constraints.csv file, then click continue.

Min Dimensions	MinHorEnclosure	MinVerEnclosure	MinHorSpacing	MinVerSpacing				
	EMPTY	power_trace	signal_trace	bonding wire pac	power_lead	signal_lead	MOS	
MinWidth	1	1	1	0	3.0	1.0	4.0	
MinLength	1	1	1	0	3.0	1.0	6.0	
MinHorExtension	1	1	1	0	3.0	1.0	4.0	
MinVerExtension	1	1	1	0	3.0	1.0	6.0	

Continue

Fig. 7 Visualization of the constraints

E. Solution Browser & Export

Now that the macro script file has been created, the GUI will automatically run PowerSynth and open the solution browser once it is completed (Fig. 9). The solution browser will draw the created layouts according to the user's selected parameters (unless initial layout evaluation was chosen, in which case solutions will be graphed by index), and the user may visualize solutions by clicking on each point on the graph. This will show the selected solution's first layer, and the user may view other layers of the same solution or a combined skeletal visualization of the layers by clicking between the tabs above the layout. Once the user has selected a solution that they wish to use, they can export either a specific solution or export all the solutions to a CSV file. This concludes the main flow for a user to create a project using the PowerSynth GUI.

Assuming the user already has a macro script file generated, they may choose to run PowerSynth directly through the GUI. Through this flow, the user will only be prompted to enter the paths for the macro script and settings.info files—mirroring the flow of the command line interface for PowerSynth. Finally, the editor presents for the provided constraints file, and after PowerSynth synthesis completes, the solution browser will display similar to the flow when creating a project.

Optimization Setup@peng.srv2

Macro Script Setup:

Floor Plan: 40 by 40

Plot Solution: ☒

Layout Generation Setup:

Layout_Mode: fixed-sized solutions

Number of layouts: 25

Seed: 10

Optimization Algorithm: NG-RANDOM

Number of Generations: 100

Open Electrical Setup Open Thermal Setup

Run Powersynth

Fig. 8 Optimization setup window

VI. Undergraduate Research Personal Experience Summary

As an REU student, my time as a POETS REU student this summer has been extremely valuable, as providing the opportunity to work in a field outside of my general studies in Computer Science and work outside of my home state at a new university has been a truly extraordinary experience. Coming from a software background, I have felt somewhat out of place compared to my peers pursuing undergraduate and graduate degrees in electrical or mechanical engineering. Despite this, my research project focusing on the development of a GUI for PowerSynth has combined my general interests in Computer Science with a tangible hardware application. While my task was focused on software design and programming, research with power module fabrication provided valuable exposure to advanced topics completely outside of Computer Science. In this way, I believe that undergraduate research can act as an effective tool for undergraduate students to fully explore career paths and topics related to, but not necessarily within the scope of their general studies.

As an inherently uncertain and exploratory time for students, the undergraduate experience in America is generally not well-built to allow for experimentation in career paths. Students are expected to select their major out of high school when they apply to college, with the knowledge that choosing undeclared when applying to a college will have its own deep-seated repercussions.

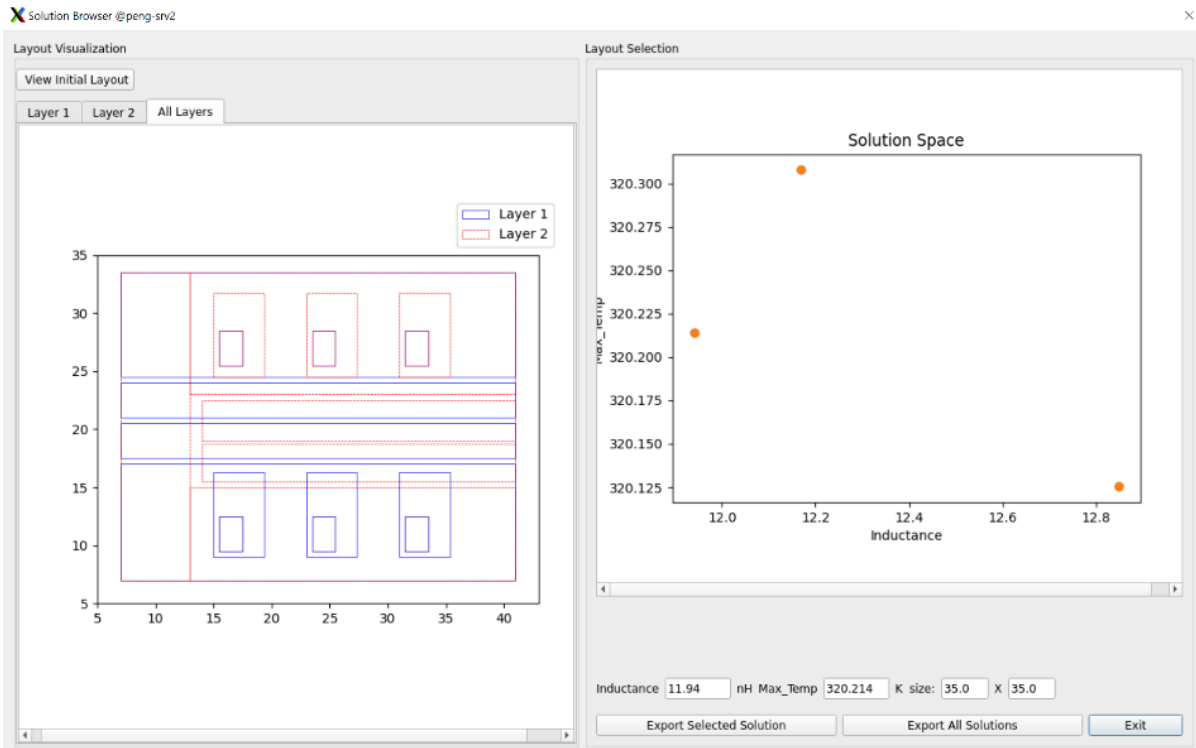


Fig. 9 Solution browser window

This difficult yet incredibly important decision often leads to student dissatisfaction and career anxiety [1]. Changing majors can be extremely difficult to impossible in some cases, perhaps best represented by some schools utilizing an actual lottery for which students are allowed to change majors due to excessive demand for popular fields. Thus, perhaps undergraduate research can fill this gap to allow for increased exploration and mentorship in new fields as the POETS REU program has for me this summer.

My in-person experience with POETS this summer is in direct contrast with the virtual research I completed in early 2020. The virtual experience had the advantage of flexibility, but personally caused greater anxiety due to a lack of effective work-life balance. My in-person experience provided many more advantages, including more effective networking, better communication between mentor and mentee, and a much more diverse learning experience. Valuable lessons from my undergraduate research experience would include the importance of a patient, available mentor, having a clear and achievable project goal, and the benefits of working outside of one's comfort zone. It should be noted that many of the benefits from my experience would likely not have been possible if the program had been virtual, and the growing acceptance of virtual programs as a replacement for direct interaction is somewhat concerning. While it is difficult to always guarantee the ability to perform in-person research given the unpredictability of outside events, it is essential for in-person research such as my summer experience to stay the norm.

VII. Conclusion and Future Work

The GUI described in this paper introduces the workflow to the user. It serves as a foundation upon which more advanced features, tools, and customizations can be added to further refine the design flow. The new GUI improves user interaction with fundamental design algorithms and data structures. Integrated into PowerSynth 2, it enhances design efficiency allowing fine-tuning and visualization of the optimized layout solutions. The goal of the project is to ease the design flow of PowerSynth for both new and advanced users, and the totality of features effectively achieves this goal.

Future features that can be added to the interface may include a visualization of the hierarchical structure of layouts to introduce the underline data structure and algorithms used in the tool. This will act as further transparency for the user to understand how PowerSynth is generating solutions. The MDKEditor may also be adapted to edit the layer stack for a project alongside the materials list. A custom layout editor to create layout script files is also currently in development and will be linked with the GUI.

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